Directed Electric Charging of Transportation using eXtreme Fast Charging (DirectXFC)

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3 June 2020

DOE Vehicle Technologies Program
Annual Merit Review

INL Lab Review System
STI#: INL/CON-20-58162

Project ID# ELT257

Overview

Timeline

- **Project start date: December 2019**
- Project end date: September 2021
- Percent complete: 20%

Barriers and Technical Targets

- eXtreme Fast Charging (XFC) is a desirable capability for PEV owners. If it is implemented without management it may have a negative impact on the grid, exasperated by variable generation
- Determine controlled and directed XFC strategies with most value to owners and grid
- Demonstrate local XFC station operation strategies for optimal energy management

Budget

- Total project funding: $ 3,000k
- DOE Share: $ 3,000k
- Contractor Share: $ 0
- Fiscal Year 2019 Funding: $ 0
- Fiscal Year 2020 Funding: $ 1,500k

Partners

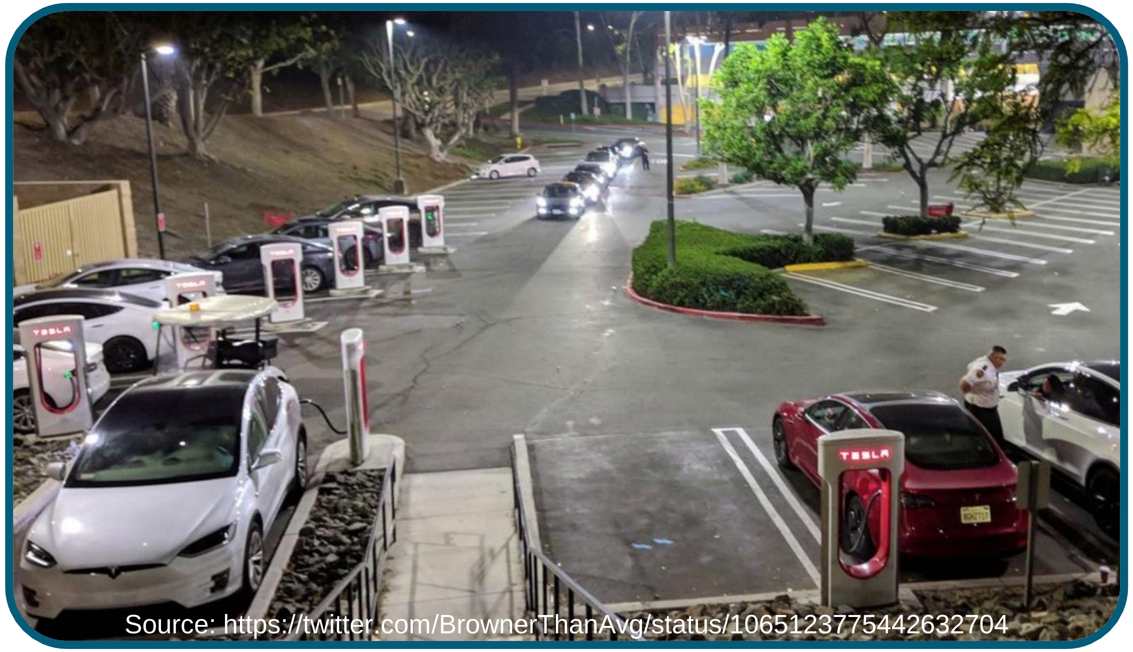
- Idaho National Laboratory (INL)
- National Renewable Energy Laboratory (NREL)
- Argonne National Laboratory (ANL)

Relevance

- More vehicles are offering XFC charging (>150kW) and more XFC stations are being installed
- As EV adoption grows and XFC usage increases, it could have a larger impact on the grid, higher charging costs for EV owners, and challenges for charge network operators

DirectXFC Objectives

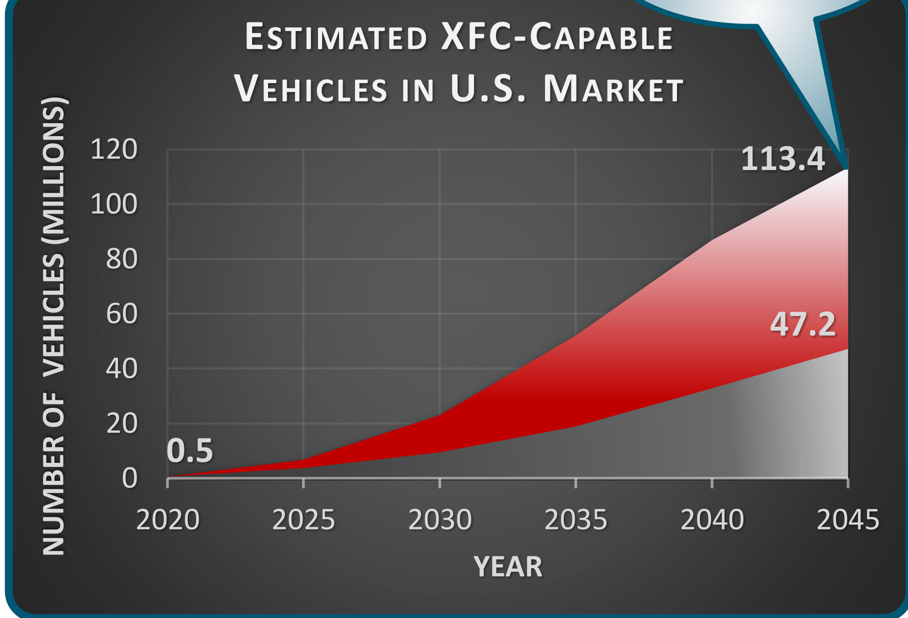
1. Determine the value of directing when and where drivers charge to minimize cost and grid impact
2. Demonstrate XFC station operation for optimal energy management
3. Determine requirements for network-level implementation and demonstrate in simulation and hardware-in-the-loop testing



Source: https://twitter.com/BrownerThanAvg/status/1065123775442632704

Introducing Caldera™, a research tool for developing and simulating XFC management strategies

100-200x increase!



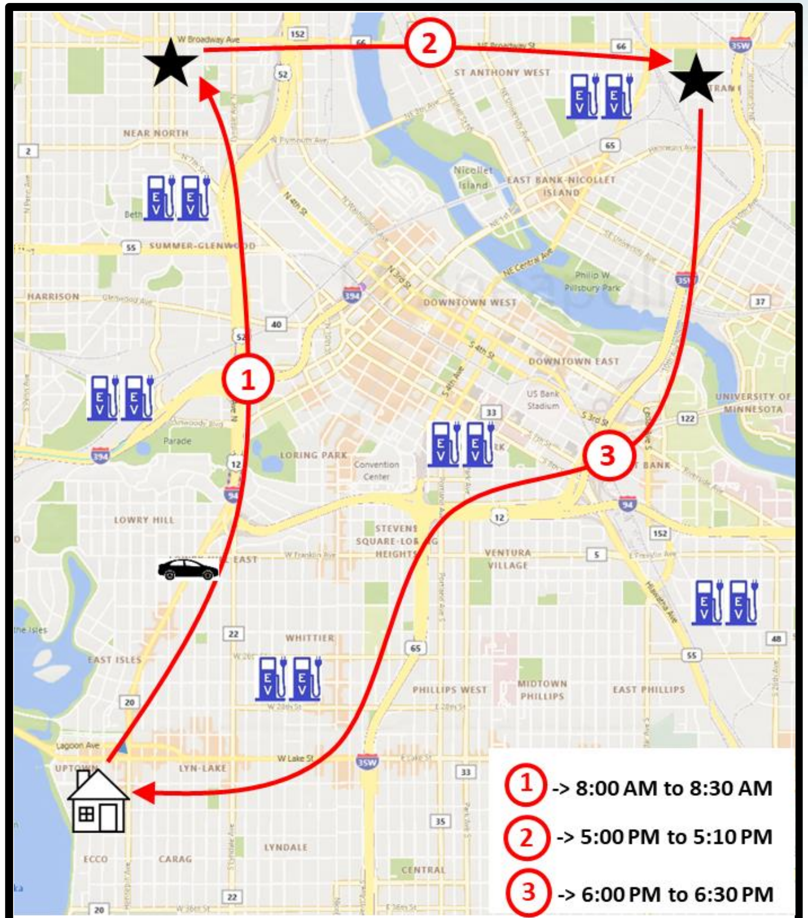
Estimates based on EPRI High/Med and DirectXFC forecasts

Milestones

Milestone	Task	Deadline	Type	Status
Define simulation scenarios for uncontrolled XFC charging at scale	1.1	3/31/2019	Quarterly	Complete
Complete creation of weekly travel itineraries, and charging station locations	1.1	6/30/2020	Quarterly	In Process
Achieve initial operational capability of XFC hardware with communication, and define ESI with utility	2.1, 2.2	9/30/2020	Annual	In Process
Demonstrate initial operational capability of directed and controlled XFC at scale in Caldera™	1.2	9/30/2020	Go/No-Go	In Process
Demonstrate co-simulation capability of controlled and uncontrolled XFC charging between Caldera™ and OpenDSS, and demonstrate XFC independent site-level integration and control	1.3, 2.3	12/31/2020	Quarterly	Next FY
Complete assessment of grid impact of scenarios in Tasks 1.1 and 1.2	1.3	3/31/2021	Quarterly	Next FY
Complete process for transferring Caldera™ network/regional-level simulation results to HIL platforms	3.1	6/30/2021	Quarterly	Next FY
Demonstrate XFC site management with distributed network and regional input (from Caldera™); develop plan for disseminating site- and network-level control strategies validated in HIL demonstrations	3.2	9/30/2021	Annual	Next FY
Publish a report quantifying the value of controlled and directed XFC charging, the extent to which XFC stations can provide grid services while still meeting charging needs; complete dissemination of validated control strategies	1.4, All	12/31/2021	Final Report	End of Project

Any proposed future work is subject to change based on funding levels.

Approach to Directing and Managing XFC



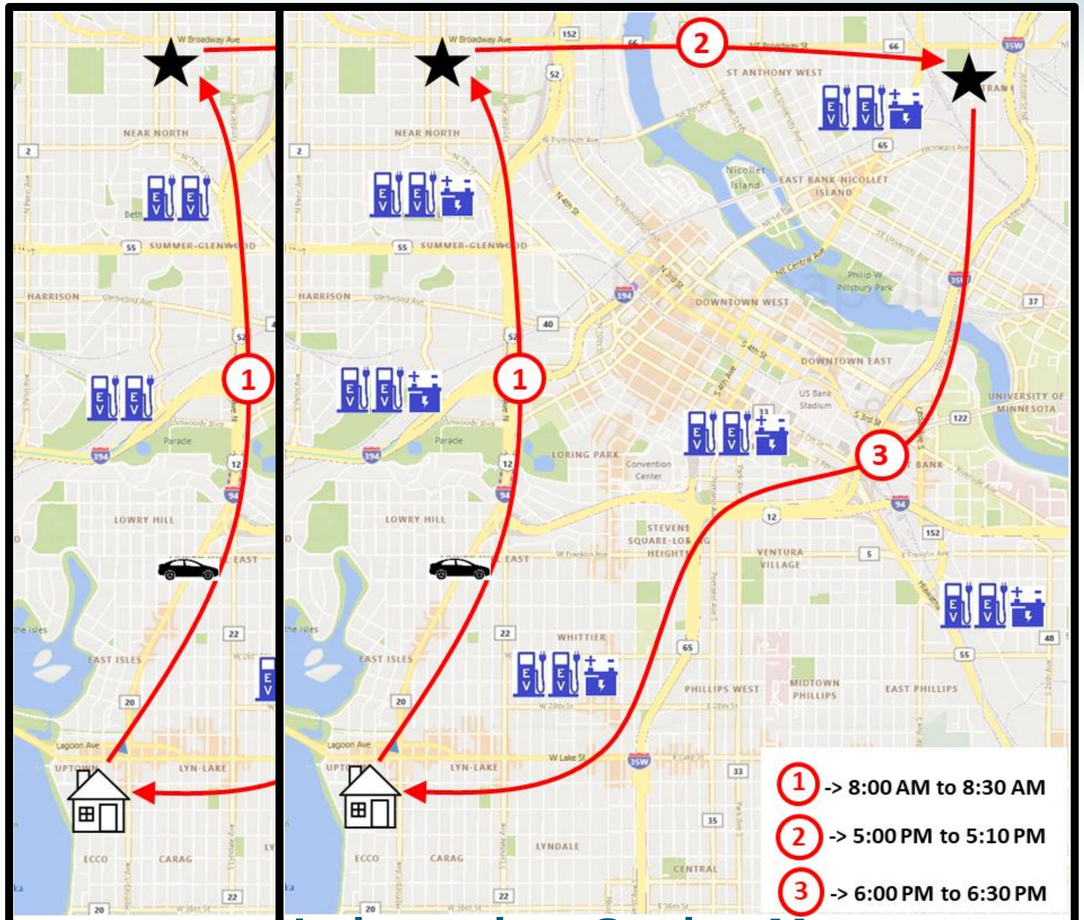
Uncontrolled

Stationary energy storage
Communication for price/availability
Reservations

Occasionally wait in line
Higher avg prices due to demand charges
Possible negative grid impacts

- Simulations conducted in Minneapolis, MN with feeder information provided by Xcel Energy
- INL's Caldera™ tool simulates vehicles selecting chargers as needed during 1-week itinerary
- NREL's OpenDSS model co-simulates effects on the distribution network

Approach to Directing and Managing XFC



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- Occasional
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Independent Station Management

- Stationary energy storage
- Communication for price/availability
- Reservations

- Smooth and reduce load profile
- Mitigate demand charges
- Grid services when not in use

- Simulations conducted in Minneapolis, MN with feeder information provided by Xcel Energy
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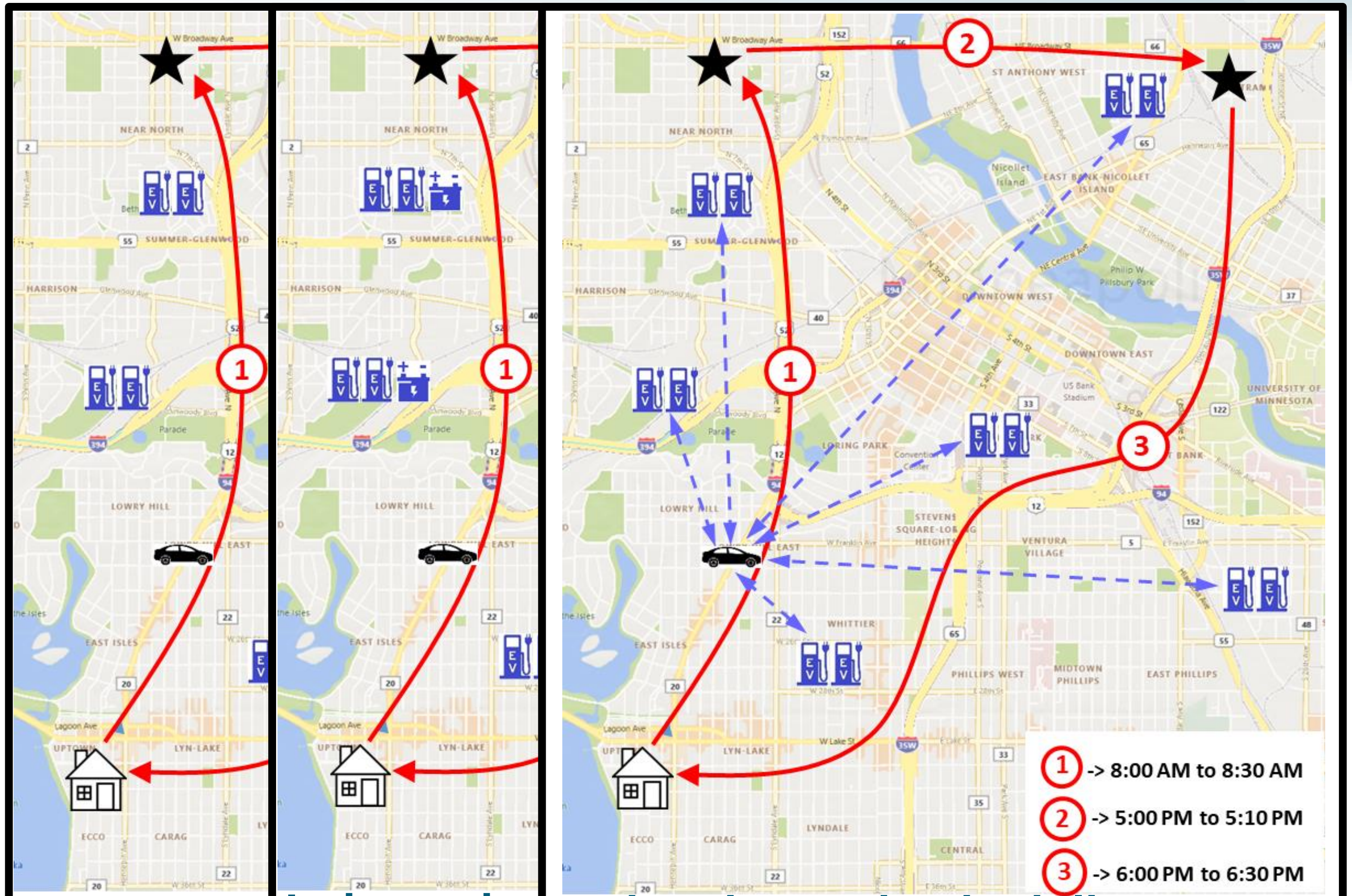
Approach to Directing and Managing XFC



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Independen
- Stationary e
- Communica
- Reservation

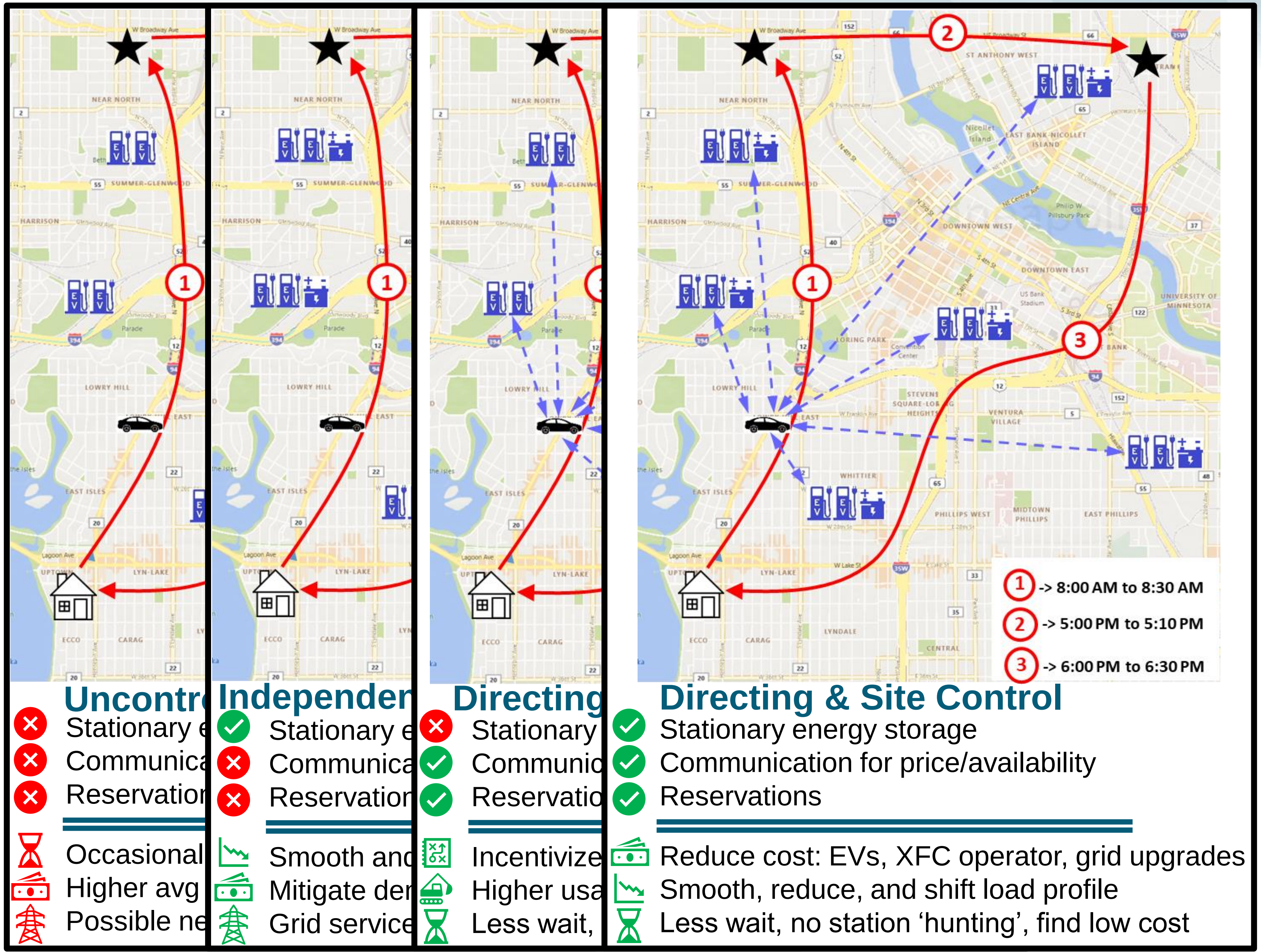
- Smooth and
- Mitigate der
- Grid service

Directing and Scheduling EVs
- Stationary energy storage
- Communication for price/availability
- Reservations

- Incentivize charging time and location
- Higher usage rates = less XFC infrastructure
- Less wait, no station 'hunting', find low cost

- Simulations conducted in Minneapolis, MN with feeder information provided by Xcel Energy
- INL's Caldera™ tool simulates vehicles selecting chargers as needed during 1-week itinerary
  - EV will communicate with EVSE networks and recommend best charging options based on market conditions
  - Caldera™ simulates owner selections to understand system impacts
- NREL's OpenDSS model co-simulates effects on the distribution network

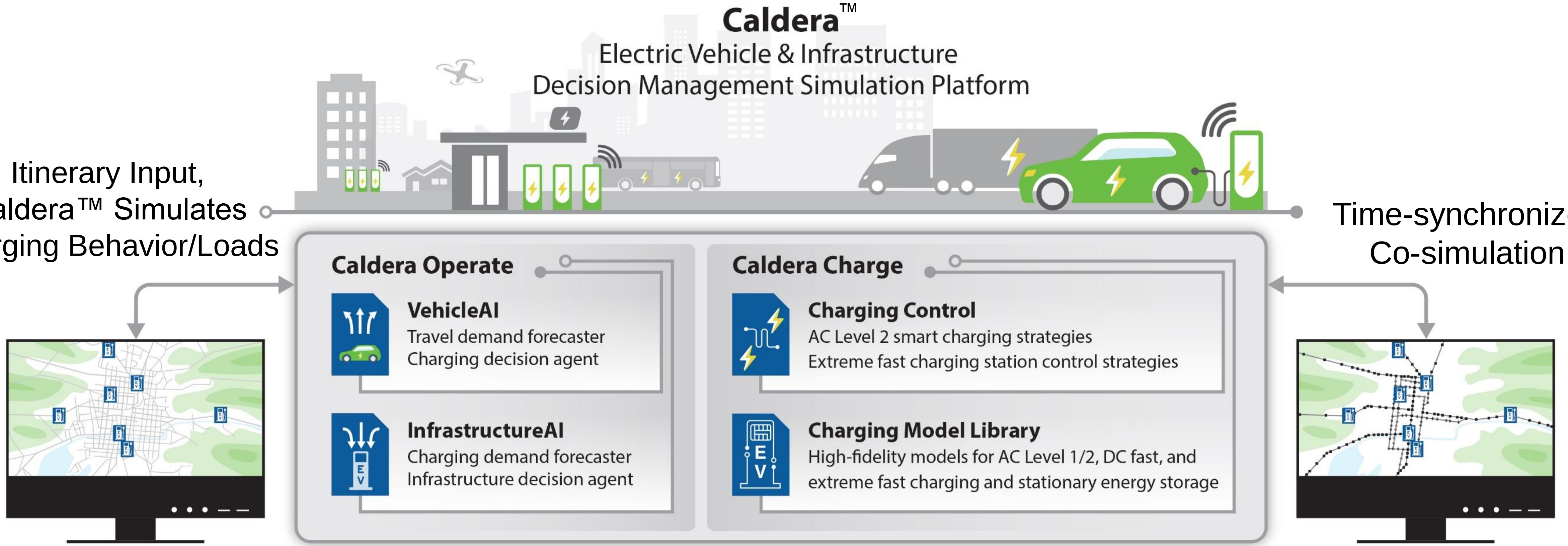
Approach to Directing and Managing XFC



- Simulations conducted in Minneapolis, MN with feeder information provided by Xcel Energy
- INL's Caldera™ tool simulates vehicles selecting chargers as needed during 1-week itinerary
  - EV will communicate with EVSE networks and recommend best charging options based on market conditions
  - Caldera™ simulates owner selections to understand system impacts
- NREL's OpenDSS model co-simulates effects on the distribution network
- NREL and ANL will conduct Hardware-in-the-Loop demonstrations of station control with the Caldera™ simulation

Approach:
Modeling and Simulation including XFC Management Strategies

Itinerary Input,
Caldera™ Simulates
Charging Behavior/Loads



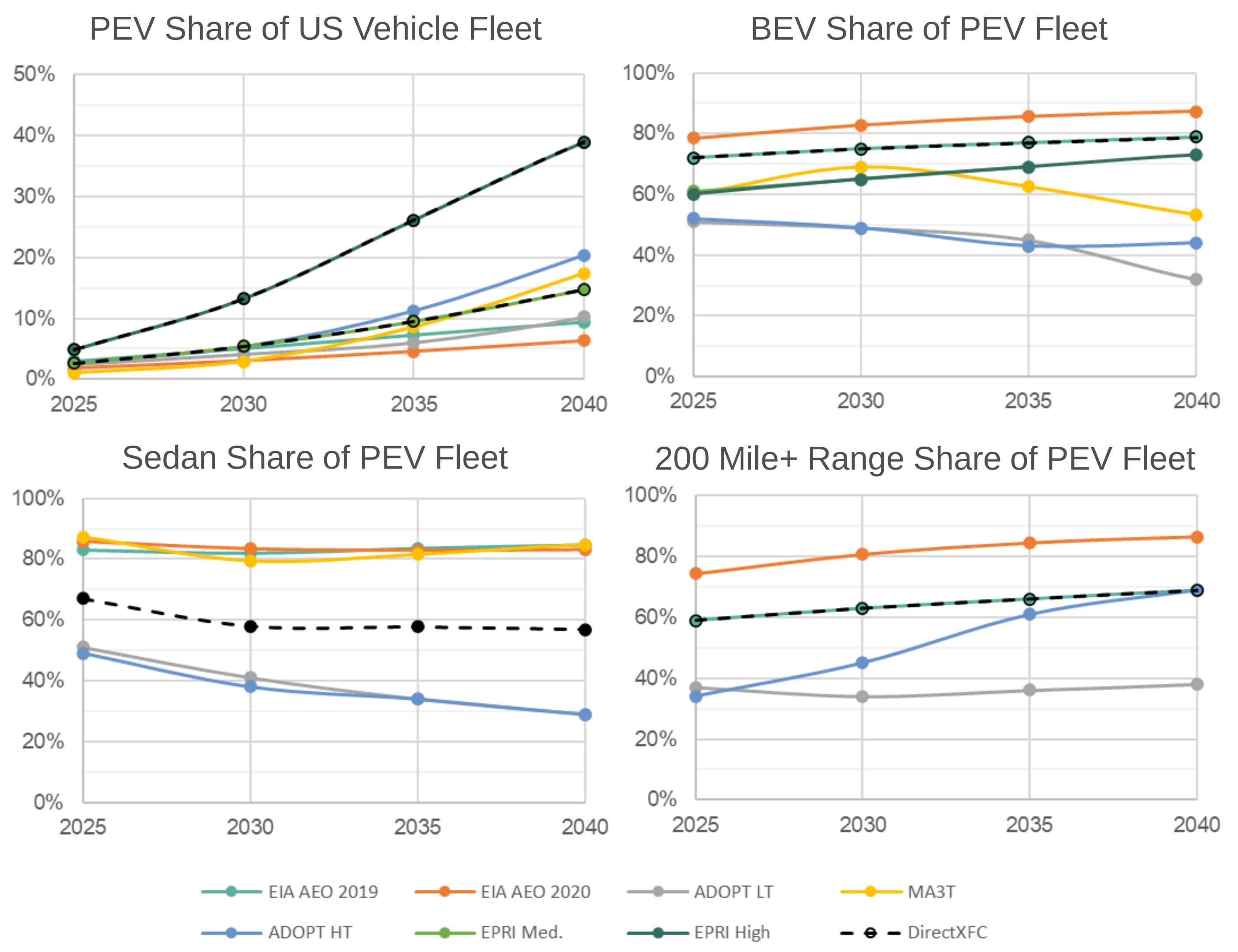
Time-synchronized
Co-simulation

Real-World Travel Data,
Realistic XFC Stations

OpenDSS Model of Xcel Energy
Minneapolis Feeders

Technical Accomplishments and Progress: Fleet Projections *(Task 1.1)*

- DirectXFC is utilizing a similar method to RECHARGE (ELT202) in selecting the total EV fleet size and composition based on the following projections:
  - US Energy Information Administration's (EIA) Annual Energy Outlook (AEO)
  - NREL's Automotive Deployment Options Projection Tool (ADOPT)
  - ORNL's Market Acceptance of Advanced Automotive Technologies (MA3T)
  - Electric Power Research Institute (EPRI) Study [1]
- DirectXFC will run 8 simulation scenarios representing the Minneapolis fleet in 2025, '30, '35, and '40 with PEV fleet sizes matching EPRI High and EPRI Medium
- The fleet characteristic selected for each applicable study year are shown in black
- Composition within the PEV fleet is guided by the 3 other graphs here and is detailed on the following slide



[1] Electric Power Research Institute, "Plug-in Electric Vehicle Market Projections: Scenarios and Impacts," EPRI Report #3002011613, https://www.epri.com/#/pages/product/3002011613/, 2017

Technical Accomplishments and Progress: Vehicle Selection *(Task 1.1)*

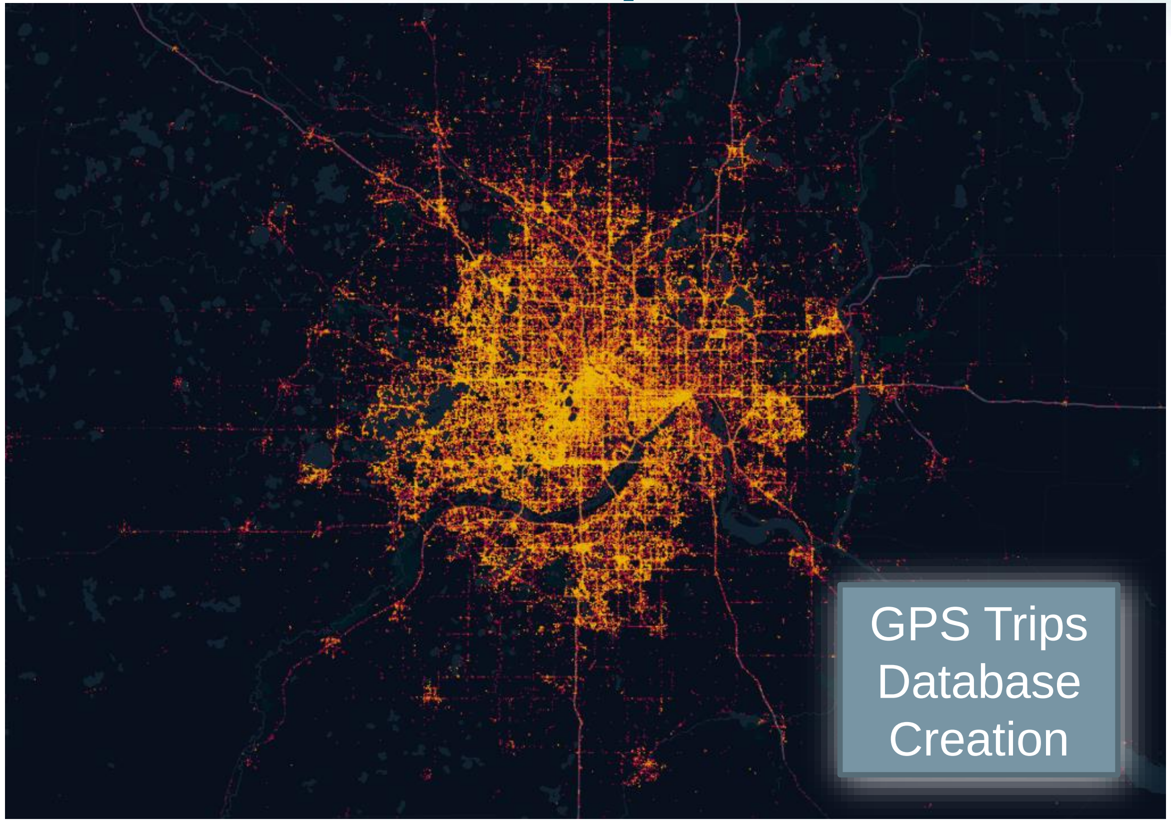
- Archetype Vehicles were defined by vehicle type, powertrain, battery capacity/EV range, charge power level, and driving efficiency
- Fleet composition percentages for 2020 are based on cumulative E-drive sales mapped as closely as possible to each vehicle type for relative reference
- Fleet composition percentages for the out years are derived to satisfy Fleet Metrics as shown on previous slide from EPRI, EIA, ADOPT, and MA3T market and consumer preference forecasts (XFC/PEV Share is a derived value)
- Gen 3 XFC charge rates allow 200 miles replenish in 10 minutes, aligning with XCEL(BAT462) goal

	Vehicle Type	EV Range (mi)	Charge Power (kW)	Driving Efficiency (Wh/mi)					
	BEV				2020[2]	2025	2030	2035	2040
XFC Gen3	Sports Car	250	400	350				1%	1%
XFC Gen3	SUV/Truck	300	575	475				6%	8%
XFC Gen3	Midsize Car	300	400	325				4%	15%
XFC Gen2	SUV/Truck	250	350	475			7%	11%	10%
XFC Gen2	Midsize Car	300	300	325			4%	12%	16%
XFC Gen2	Compact Car	150	150	300			5%	6%	10%
XFC Gen1	Sports Car	250	300	350		1%	1%	1%	0%
XFC Gen1	SUV/Truck	200	150	475	7%	25%	24%	13%	9%
XFC Gen1	Midsize Car	275	150	300	32%	27%	23%	19%	10%
DCFC	Compact Car	250	75	300	4%	6%	4%	2%	
DCFC	Compact Car	150	50	300	18%	13%	7%	3%	
	PHEV				2020	2025	2030	2035	2040
AC Only	SUV/Truck	50	Do not fast charge	475	5%	8%	11%	13%	16%
AC Only	Midsize Car	50	Do not fast charge	310	14%	13%	9%	8%	5%
AC Only	Midsize Car	20	Do not fast charge	250	20%	7%	5%	2%	

[2] E-drive: https://www.anl.gov/es/light-duty-electric-drive-vehicles-monthly-sales-updates

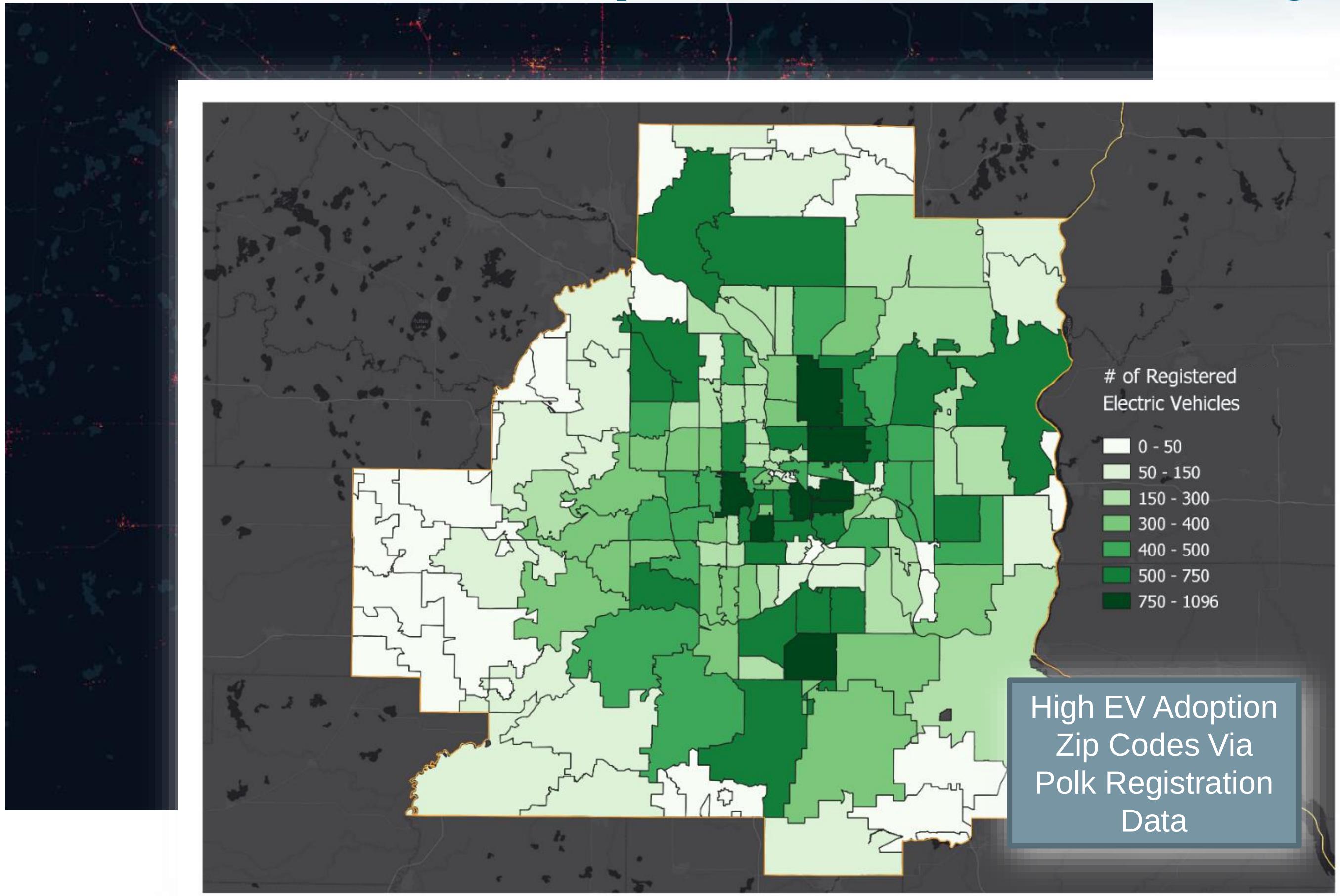
Fleet Metrics	2025	2030	2035	2040
BEV/PEV Ratio	72%	75%	77%	79%
BEV200+/PEV Ratio	59%	63%	68%	69%
Sedan PEV Share	67%	58%	57%	57%
XFC/PEV Share	53%	64%	72%	79%

Technical Accomplishments and Progress: Vehicle Home Assignment (Task 1.1)



Minneapolis, MN

Technical Accomplishments and Progress: Vehicle Home Assignment (Task 1.1)



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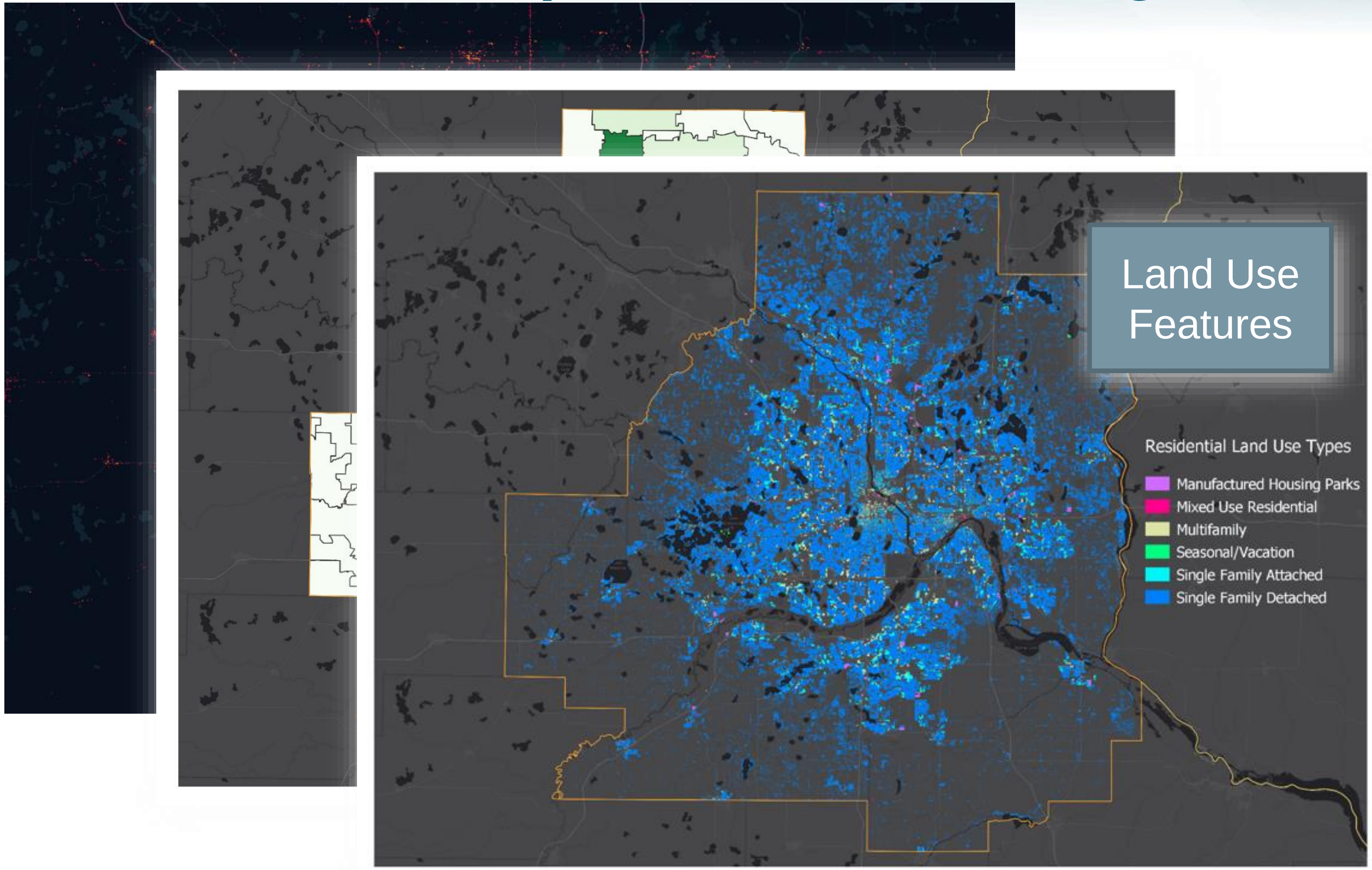

Minneapolis, MN

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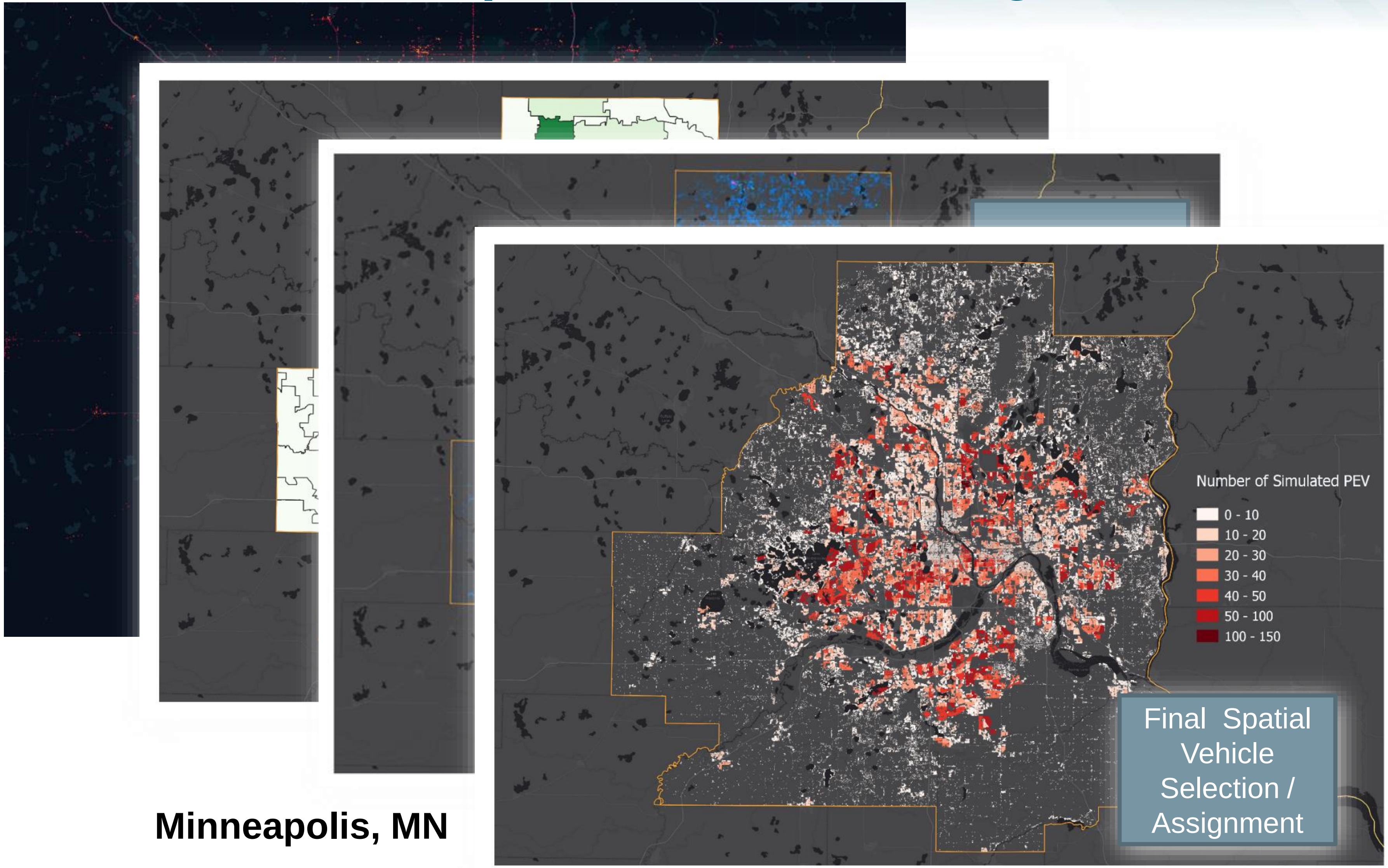

Minneapolis, MN

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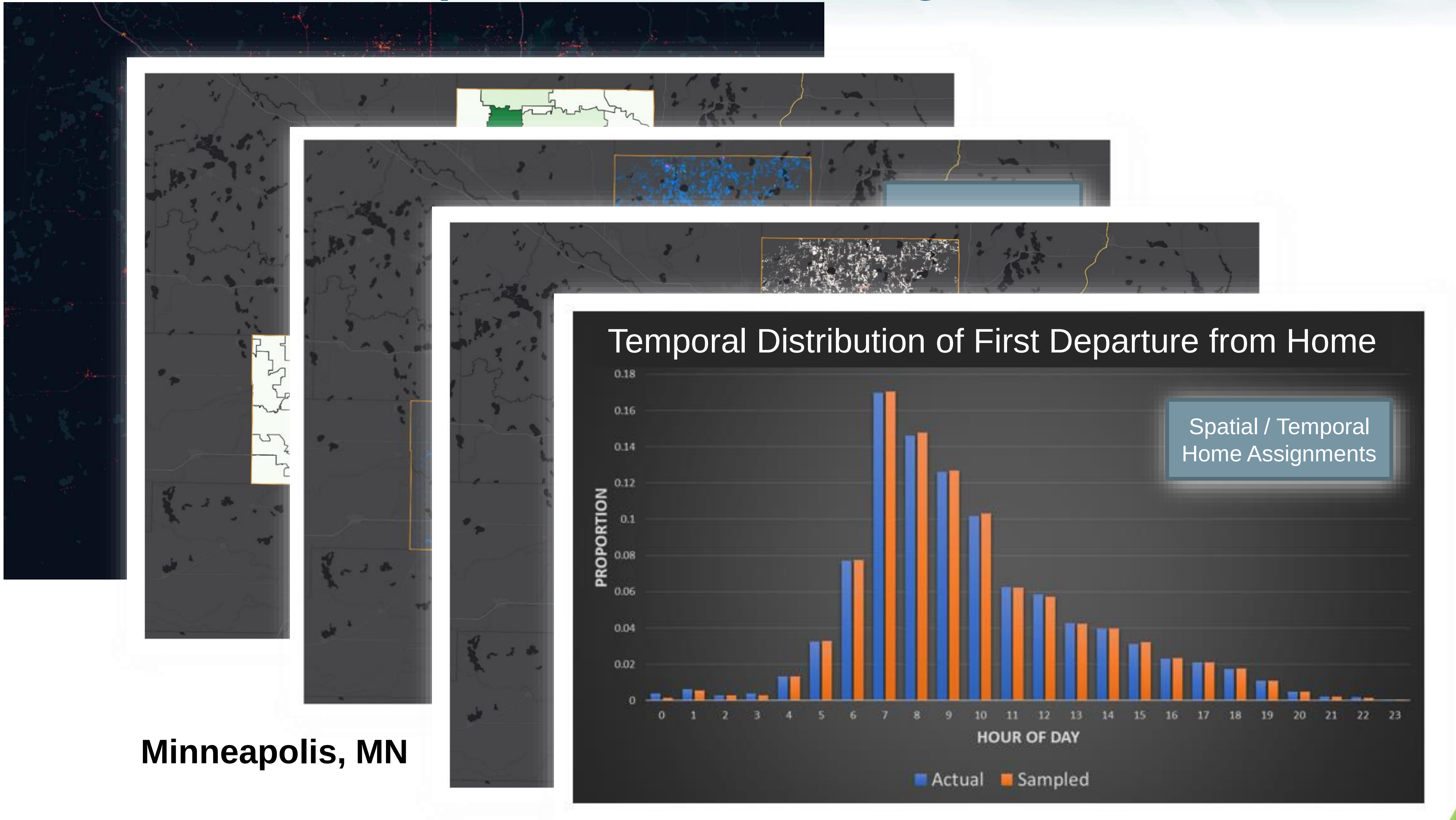
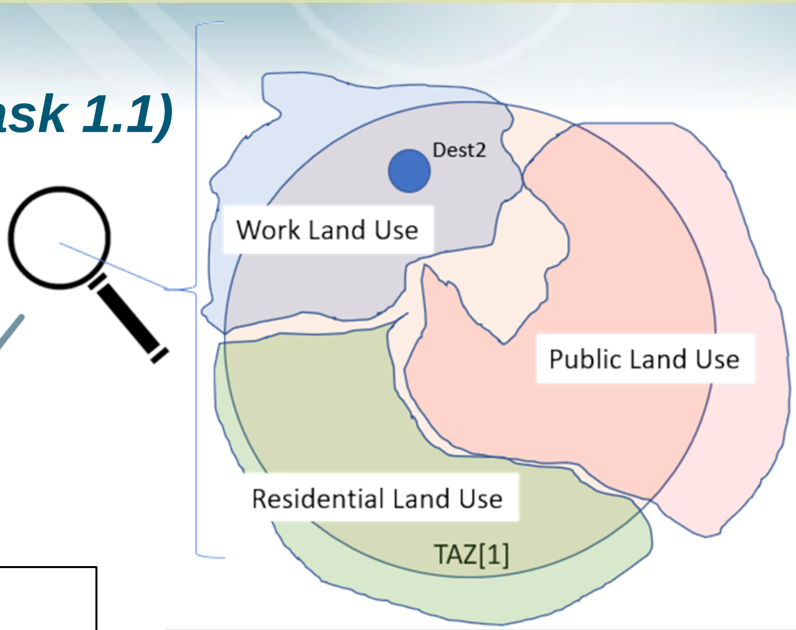


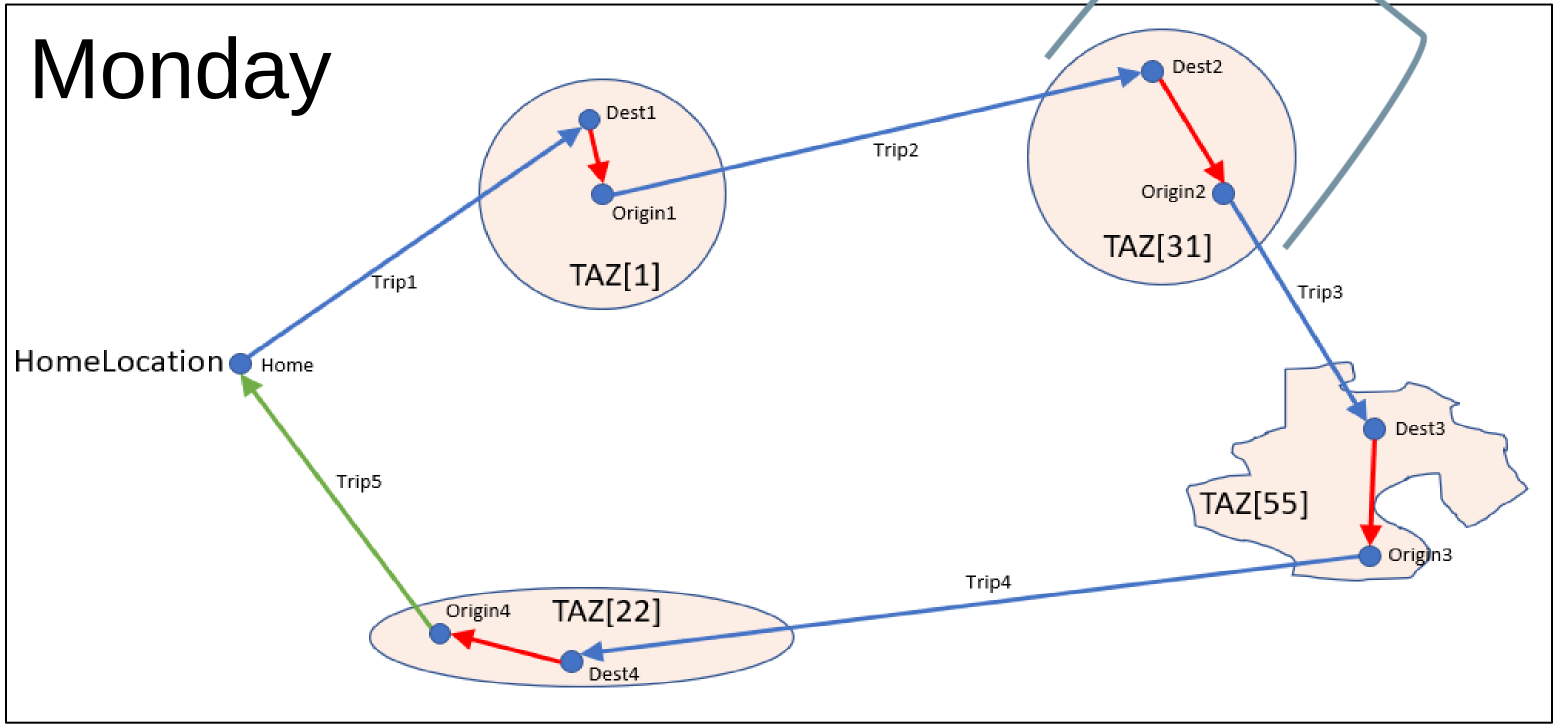
Minneapolis, MN

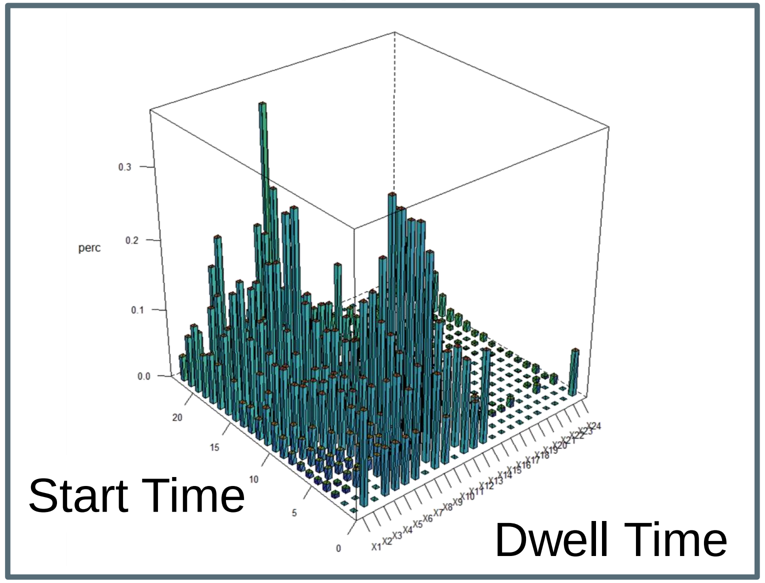
Technical Accomplishments and Progress: Trip Chaining (ZEP) – Itinerary Generation (Task 1.1)

Stochastic process using immutable OD pairs to generate travel data

- Governed primarily by dwell time distributions
- Vehicles have a known start time / return time
- Vehicles travel and dwell at different locations and at return time vehicles are sent home
- Survey based probability distributions will determine repeatability of driver behavior

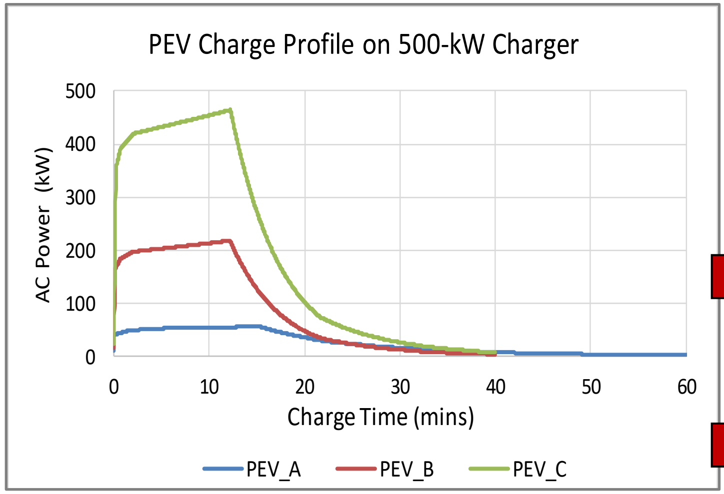






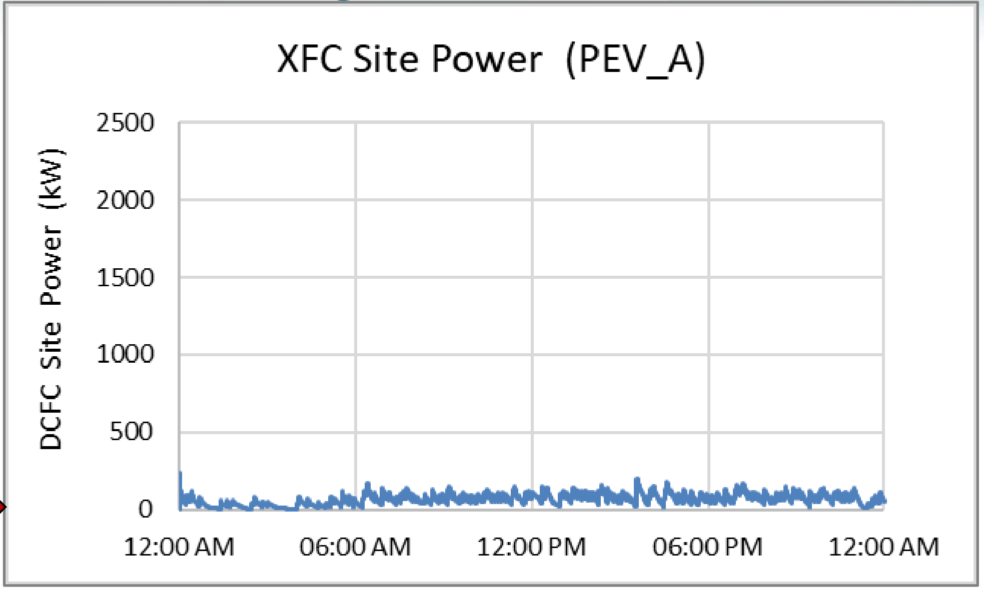
Technical Accomplishments and Progress: Load Shapes for XFC Site
(Task 2.3)

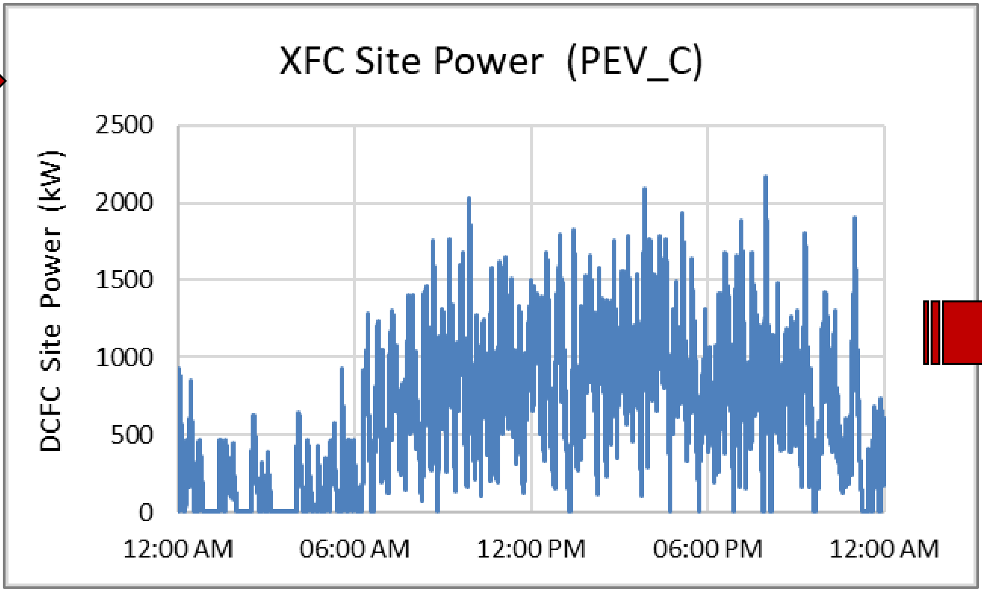
XFC Charge Profiles for Hypothetical Vehicle Classes



	PEV_A	PEV_B	PEV_C
kW	50	200	400
kWh	22	54	115
Chemistry	LMO	NMC	NMC

Results from Caldera™

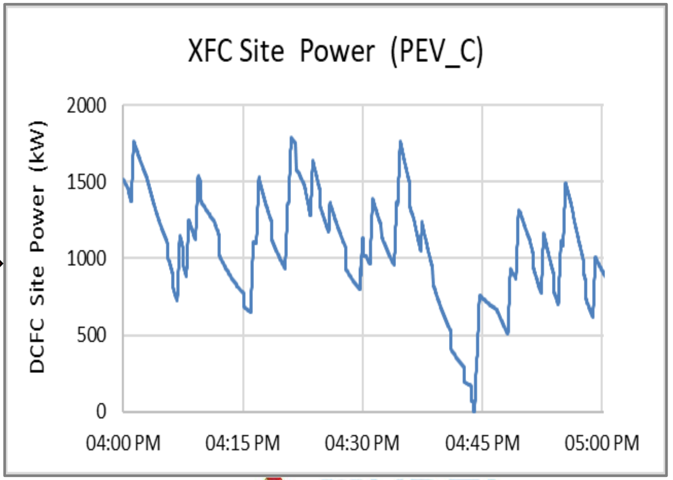




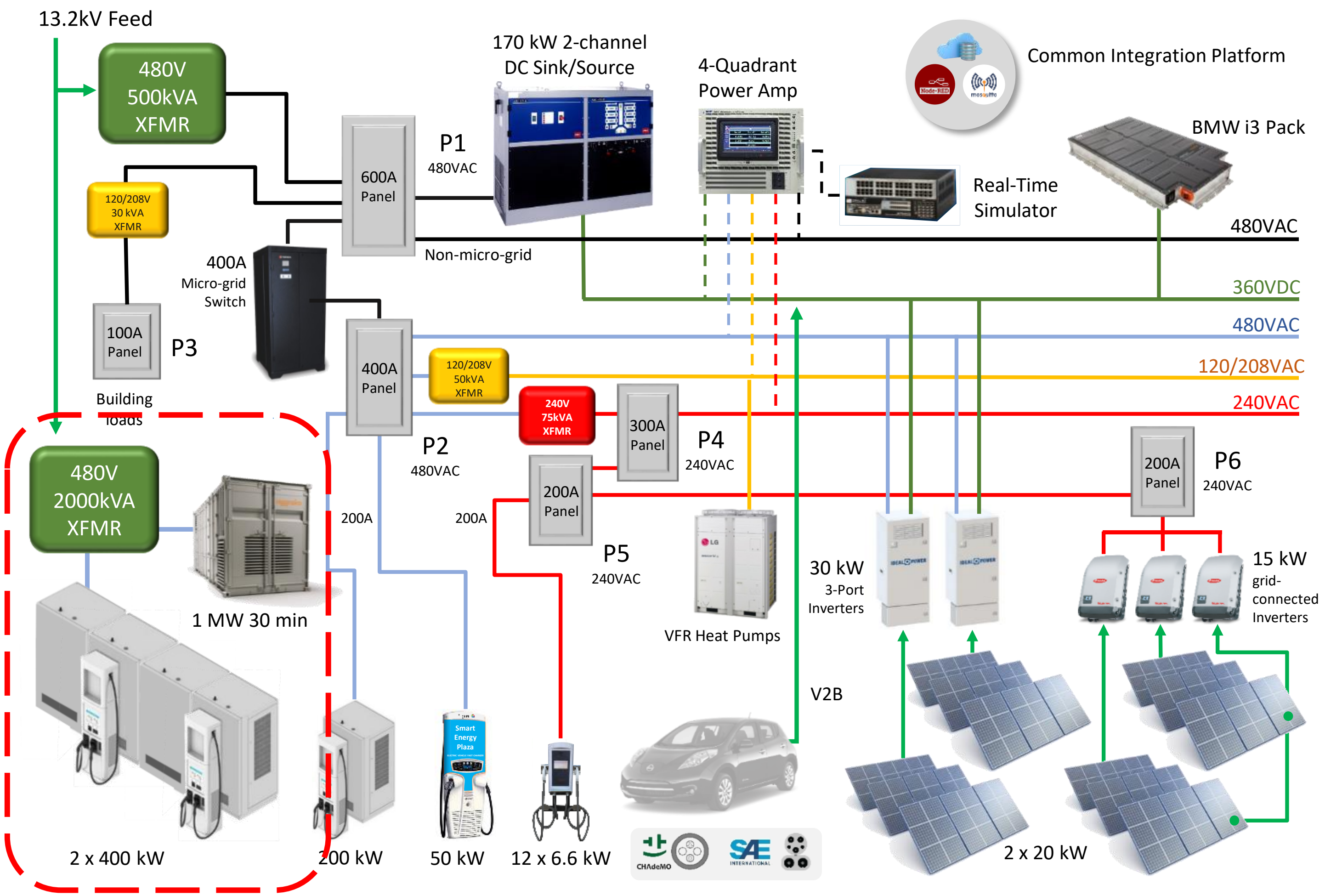
Caldera™ Simulation included:

- 5 x 500 kW chargers located at XFC station
- Vehicle use from FY17 EPSA project, based on real-world gas station use
- Magnified view shows abrupt ramping and high peaks for highest charge rate

- Local station controls including Battery Energy Storage System (BESS) and power electronics can smooth and reduce peaks



Technical Accomplishments and Progress: XFC Hardware @ Argonne Smart Energy Plaza (Task 2.3)

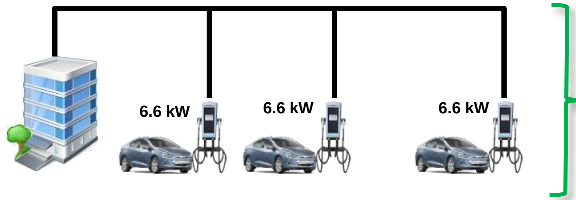


Addition of XFC and Battery Energy Storage System (BESS) at Argonne Energy Plaza

- Acquisition and/or installations in process
  - Two 400 kW DC EVSE
  - 2000/2667kVA transformer and switchgear
  - 1 MW-30 minute battery

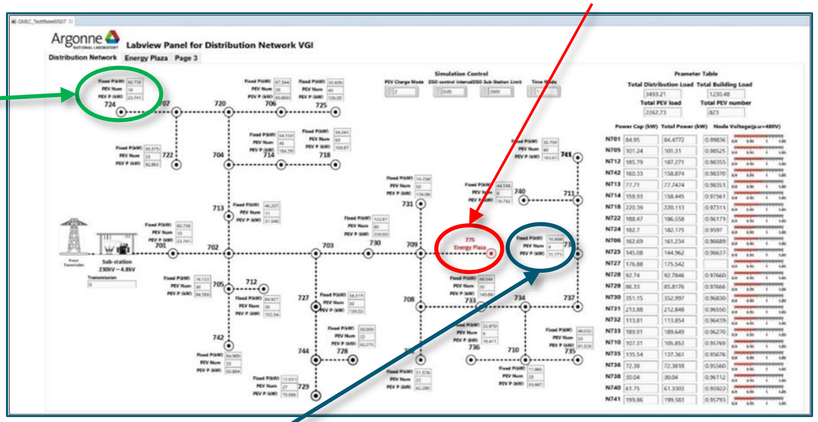
Technical Accomplishments and Progress: Distribution Feeder Network including ANL Energy Plaza (Task 2.1)

Virtual Node 724 (Commercial/Residential area)

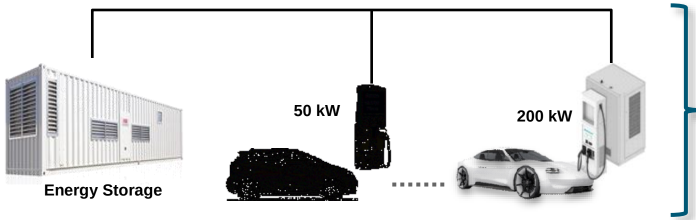


- Buildings
- 20 to 40 EVs
- AC L2 EVSE
- Power curtailment with managed charging

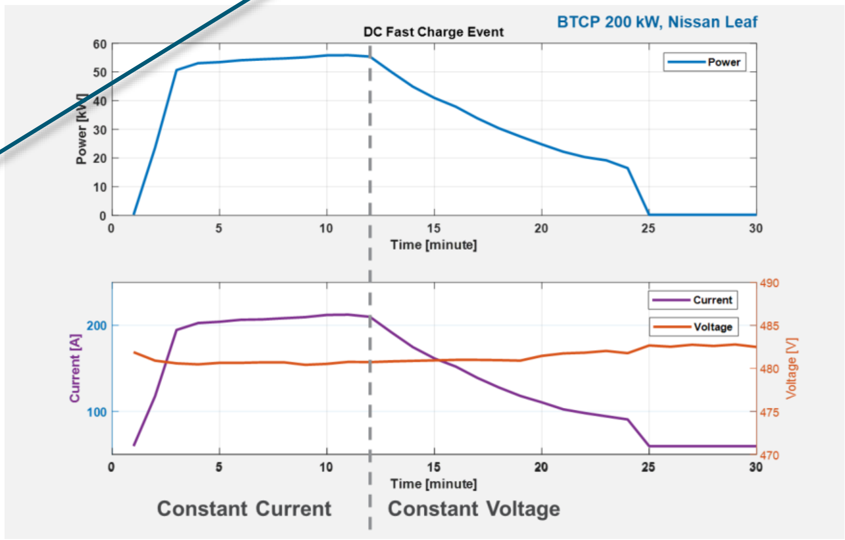
Real Node 775 (Energy Plaza)



Virtual Node 738 (Fast Charge station)



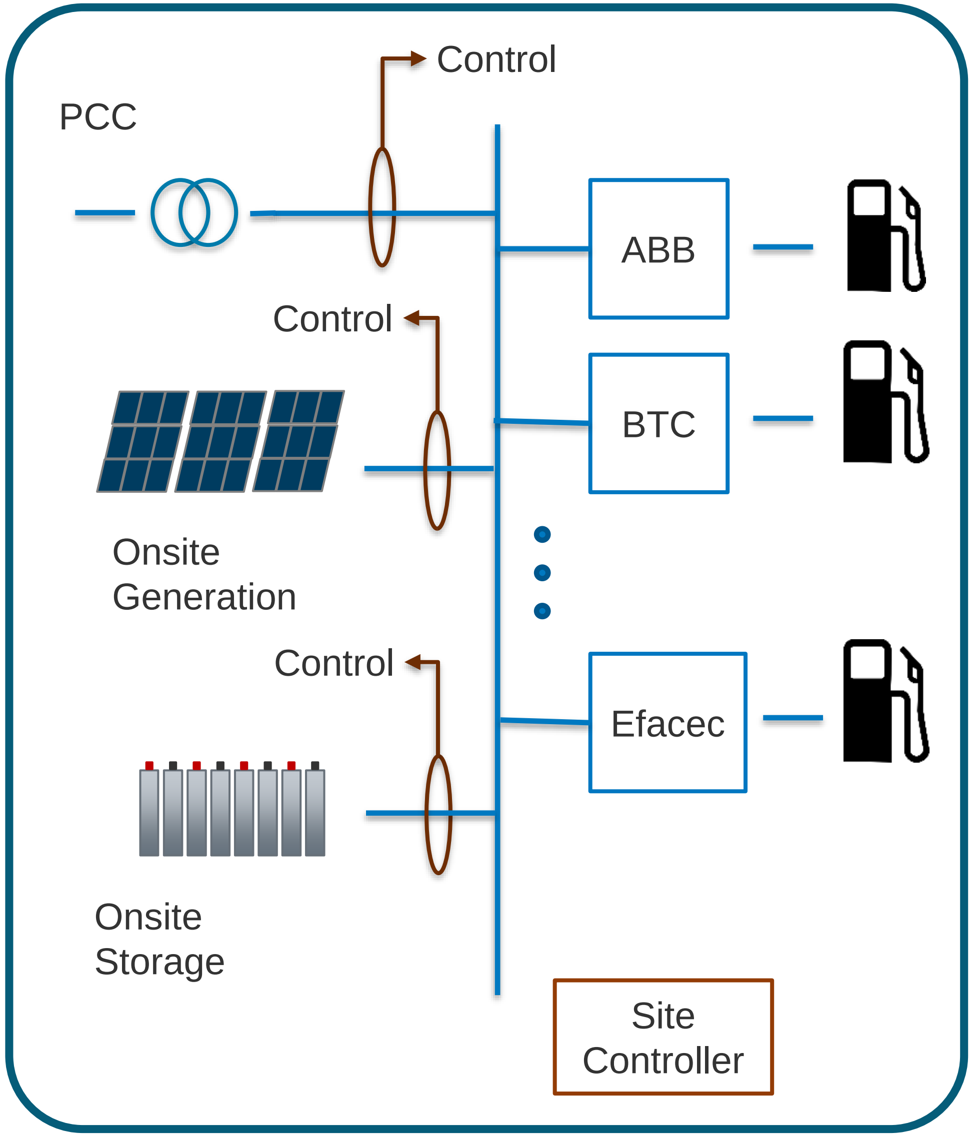
- Up to 10 EVs
- DC FC: 50 kW and 200 kW
- Max EVSE power with managed storage



Defined linkage between INL Caldera and ANL DNM (Distributed Network Model)

- DNM (Smart VGI)
  - Leverage charging stations with XFC and battery storage
- Caldera (from Task 1)
  - Temporal and spatial PEV charging behavior
  - Charging profiles (real and reactive power)

Technical Accomplishments and Progress:
Development of integrated control of NREL XFC station / site (Task 2.1)



Load and generation estimation is required for optimal energy storage integration

- **DCFC load** will vary depending on charging infrastructure and travel patterns
- Onsite **renewable generation** will be dependent on regional conditions

Control integration is required for energy system and onsite generation management

- **Interoperability** of communication and control across different vendor HPFC systems.
- Resolving **multi-objective optimization** across the site, transportation, and grid interface.

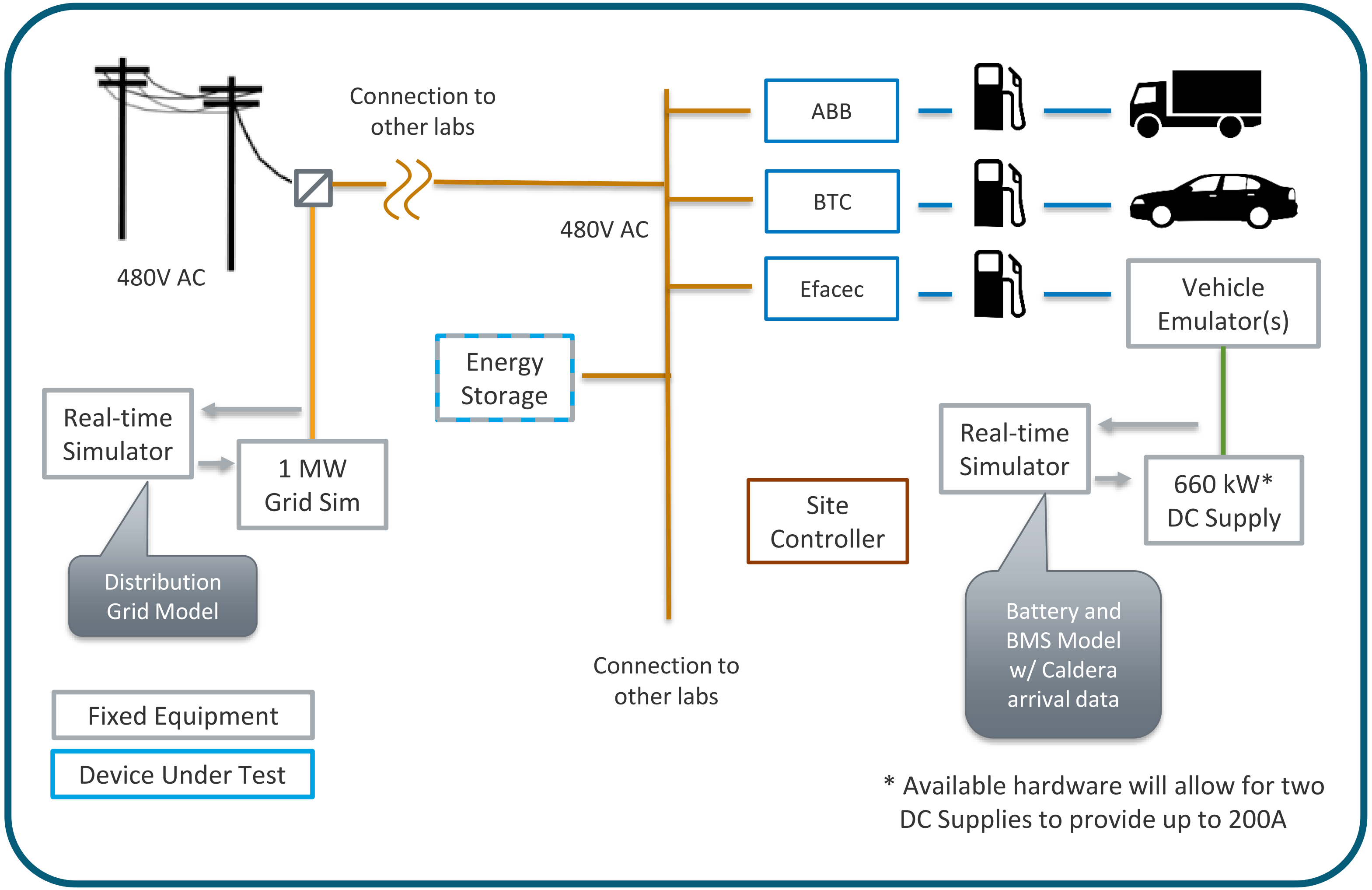
Task will develop network connectivity and control methodologies to manage an XFC site to verify Task 1.2 results at a station-level.

Technical Accomplishments and Progress:
Implementation of XFC station management @ NREL (Task 2.3)

Lab Connection to DC Supply and Charger Power Conversion

XFC Charging Dispenser

Vehicle Emulation Hardware (replicates vehicle being charged by XFC Station)



Response to Previous Year Reviewers' Comments

New project started in FY20, not previously reviewed

Collaboration and Coordination

INL is leading this project and developing the simulation platform – Caldera™, charging load profiles, and charge management control strategies

NREL is creating the simulation scenario inputs, operating their MN OpenDSS model from RECHARGE as well as developing a HIL demonstration of XFC site implementation

ANL is assessing the network-level requirements and impacts of XFC control as well as developing a HIL XFC station for real-time grid impact analysis with their Distributed Network Model used in SmartVGI

The PEV adoption and fleet make-up used in DirectXFC simulations were chosen in coordination with other DOE funded projects: RECHARGE(ELT202), Behind The Meter Storage (BTMS-BAT422), XCEL(BAT462), and VTO Analysis E-drive sales tracking

The DirectXFC team also coordinates with Automotive and Utility partners on the USDRIVE Grid Interaction Tech Team (GITT)

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

Idaho National Laboratory

- Tim Pennington
- Don Scoffield
- Zonggen Yi
- Manoj Kumar

NREL – NATIONAL RENEWABLE ENERGY LABORATORY

- Andrew Meintz
- Chris Neuman
- Kalpesh Chaudhari
- Jesse Bennet
- Shibani Ghosh
- Shivam Gupta
- Keith Davidson

Argonne NATIONAL LABORATORY

- Keith Hardy
- Dan Dobrzynski
- Jason Harper

Remaining Challenges and Barriers

- Co-simulation needs to be implemented
- Hardware-in-the-loop demonstrations have construction and communication risks
- COVID-19 and the Labs’ safety posture poses risk to physical work on hardware
- Results of uncontrolled charging simulations must be factored into control strategies
- Input from industry is being sought for vehicle/charging station communications and business planning efforts for increased XFC – competitive sensitivities may obstruct information sharing

Proposed Future Research

ID	Task	Description
1	**Determine the value of managed XFC for customers and the grid**	
1.1	Uncontrolled XFC charging at scale	Caldera™ simulation of Minneapolis EVs in uncontrolled 2025-2040 scenarios
1.2	Controlled and directed XFC charging at scale	Development and implementation of Site Control Strategies and EV Directed Strategies in Simulation
1.3	XFC grid impact and grid services	Co-Simulation of Caldera™ with OpenDSS model for Minneapolis Feeders to assess impact and services
1.4	Value analysis	Analytical assessment of value offered by each management method and scenario
2	**XFC station/site implementation(s) for optimal energy management**	
2.1	Development of integrated control of XFC site	Planning and development of hardware control for XFC sites
2.2	Requirements for site-level energy services interface	Interface and communication for XFC site and energy services
2.3	Implementation of XFC station management	Demonstrate independent site management strategies through laboratory testing
3	**Network-level requirements and impact of XFC integration**	
3.1	Requirements for network-level interfaces	Development of communication interfaces for networked control of XFC site
3.2	Network-level control hardware-in-the-loop demonstration	Demonstrate network-level control of XFC site through HIL testing between Caldera™ and lab XFCs

Any proposed future work is subject to change based on funding levels.

Summary

- eXtreme Fast Charing (XFC) enables long distance trips and convenient charging when needed, especially for those without access to home charging
- DirectXFC and Caldera™ are assessing the impact of these high-power loads
- A new paradigm for managing fast charging
  - Communication between EV and EVSE to assist in making optimal market-based charge decisions, best for the driver and the grid
  - Communicated decisions (reservations) provide reliable forecasts for optimal management of the stations’ energy

- Technical Highlights
  - Coordinated data across projects creates harmonized research for comparable results
  - Caldera™ development offers future benefits to other charging infrastructure research

- Impacts of VTO efforts
  - Value to Grid, XFC Operators, EV owners and Infrastructure System
  - Simulation useful for future planning
  - Communication and Reservation system has technology transfer potential
  - Site control useful innovation to industry
  - Integrated control useful to utilities

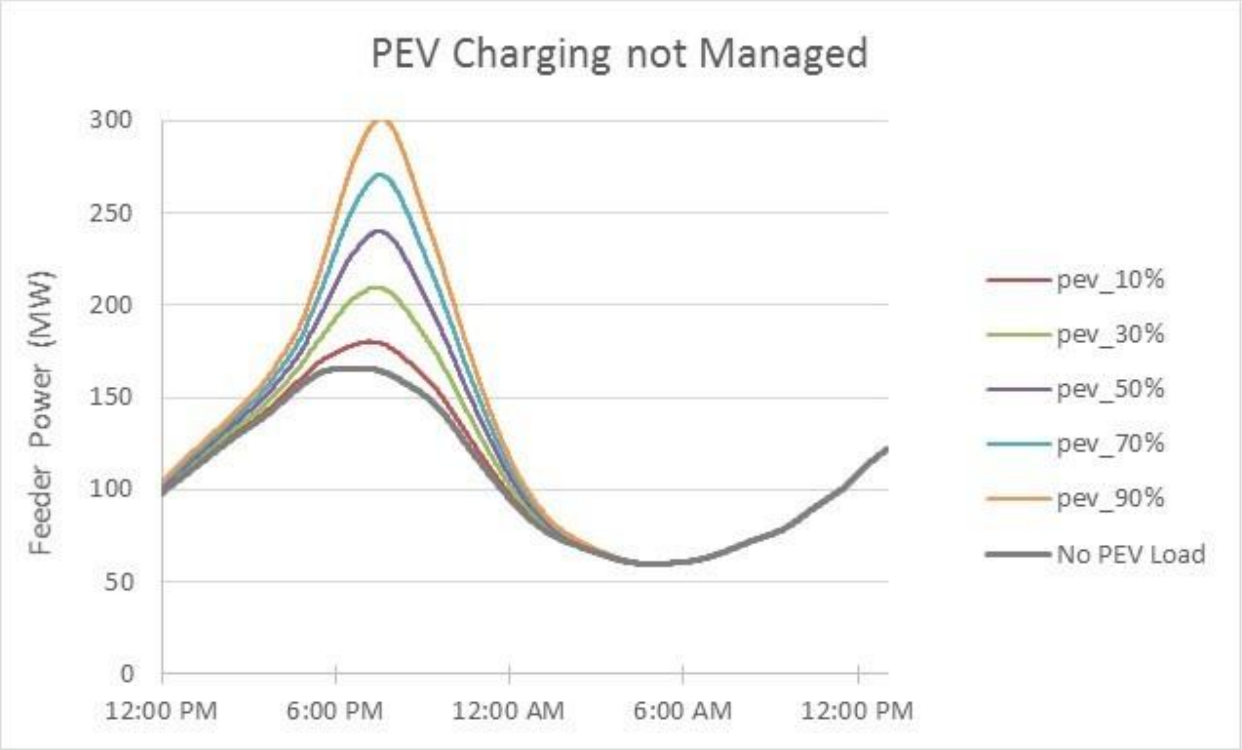
Technical Back-Up Slides

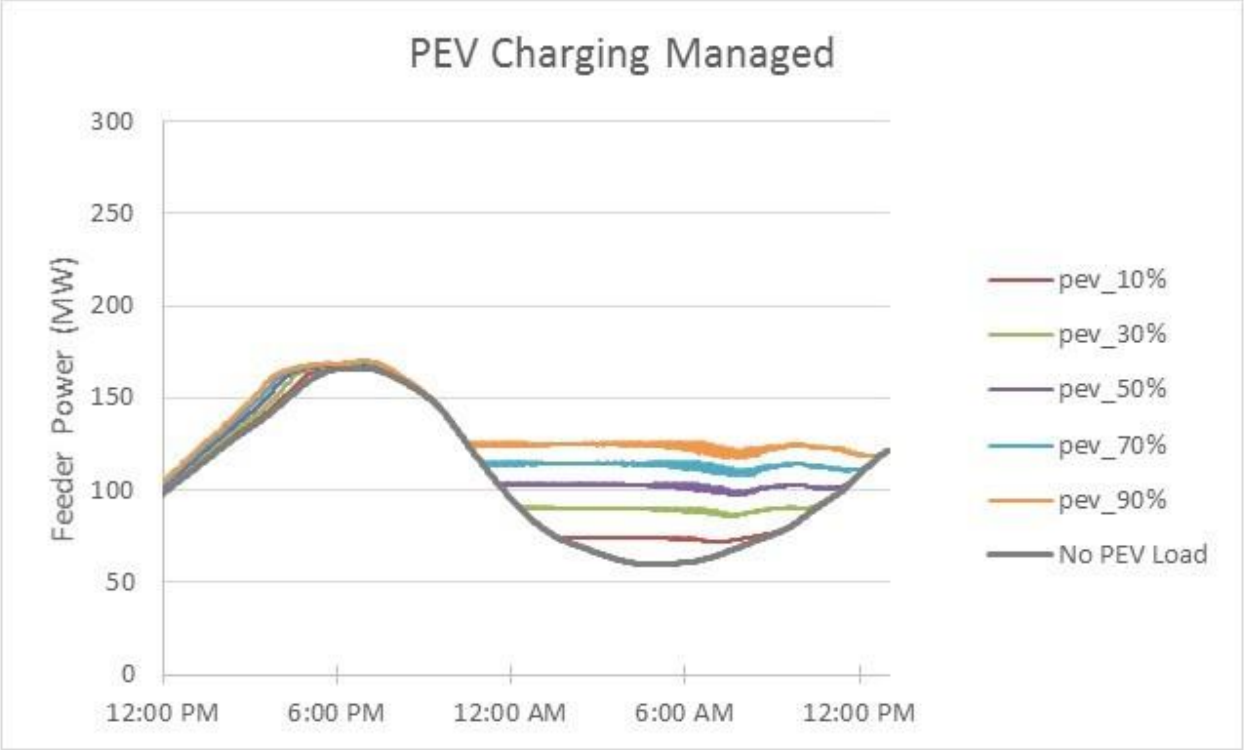
www.inl.gov

Idaho National Laboratory

PEV Charging Controls Development in Caldera™

- Caldera™ enables realistic PEV charging controls development considering both transportation system and grid conditions

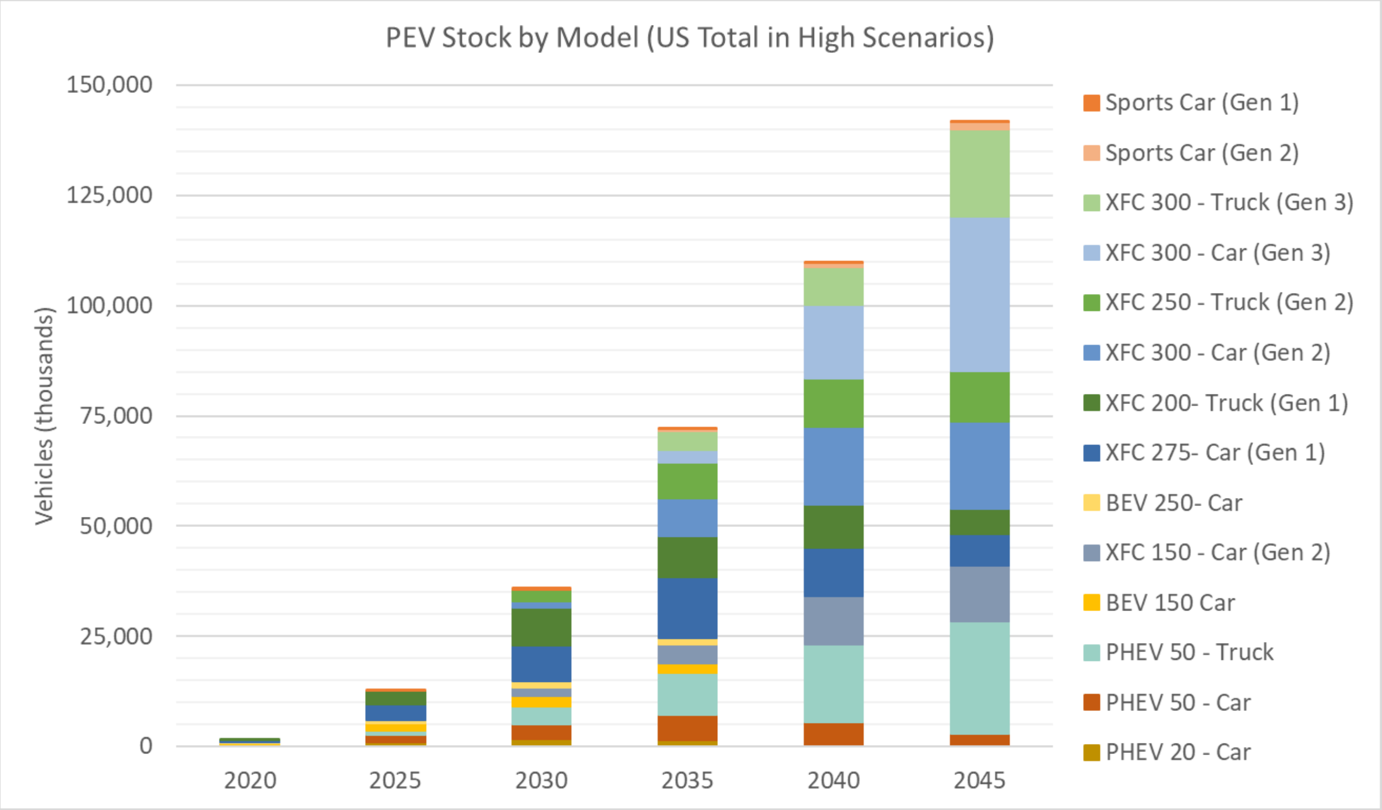




Comparison of controlled and uncontrolled PEV charging using the level 2 charging centralized control strategy developed in the DOE Funded GM0085 project

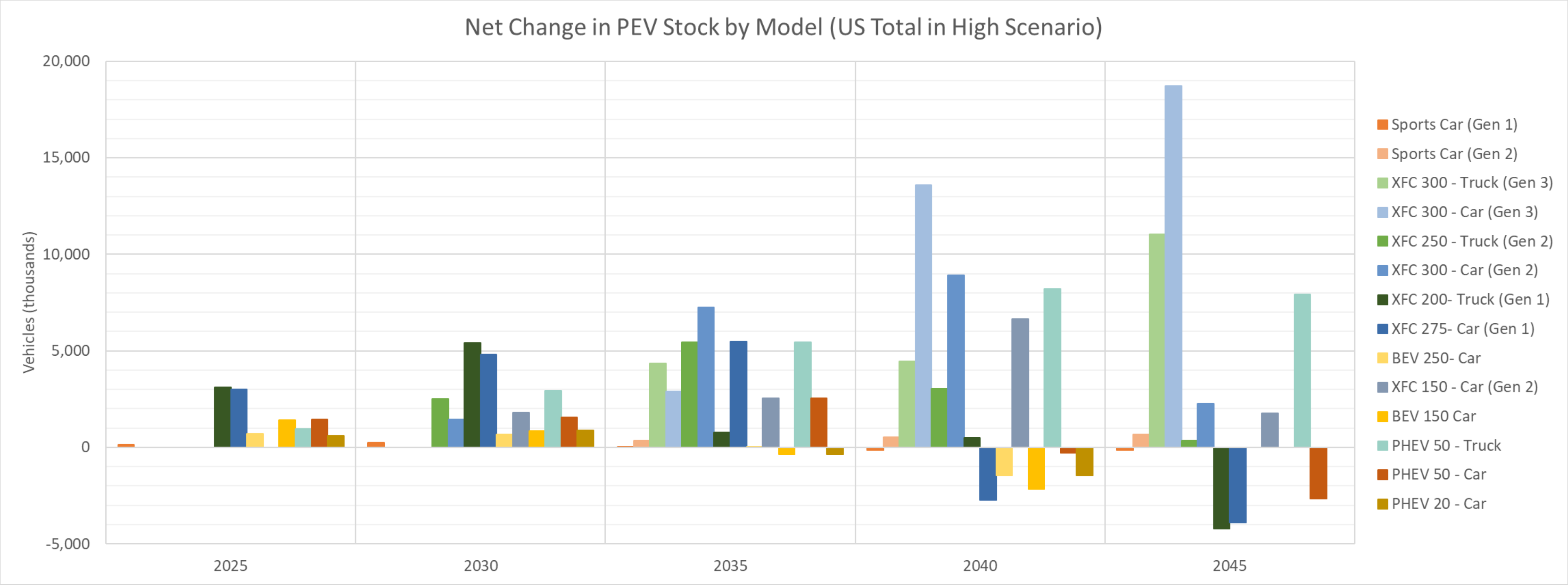
Technical Back-up Slides: PEV Fleet Growth

- PEV Stock growth broken down by model type
- Key Highlights
  - XFC Car & SUV models
    - Gen 2 after 2025
    - Gen 3 after 2030
  - PHEV Truck and XFC Car Gen2 reach highest total vehicle adoption at 18% and 16% in 2045
  - PHEV20, BEV 250, and BEV150 phased out by 2040



Technical Back-up Slides:
PEV Market Growth

- Net change in PEV Stock by model type in 5-year intervals accounting for new sales and retired vehicles
- EIA's AEO 2019 reference case ranges from 71.3 to 77.9 million car and truck sales for the 5-year intervals from 2025-2029 and 2045-2049

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